CLASSIFICATION OF SPRINGS[1]

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INTRODUCTION

Among the common phenomena of nature, springs are notable because of their high usefulness. Since the earliest times the homes of men have clustered around them. In arid regions their number and size may limit the population. In many humid regions springs are so numerous and similar that distinctions between them are not recognized, yet they may be caused by so many principal and minor factors or by so many combinations of these factors as to make the origin of any one spring exceedingly complex or obscure. An interesting account of the many erroneous

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notions held by the ancients regarding the origin of springs can be found in Paramelle.[1] In addition, their very familiarity has brought about an indifference which has led the average investigator to pass them by. Only springs with unusual characteristics have been thought worth study. Elaborate classifications have been suggested for so-called mineral springs—those whose water is exceptional because of gas or mineral content—but a complete classification of all springs has been attempted only by Keilhack.[2] His classes are not mutually exclusive, and his primary division into descending (*absteigende*) springs and ascending (*aufsteigende*) springs separates, not waters of unlike origin, but only waters that have unlike paths to the surface. A number of authors have made incomplete classifications for the springs of a limited region or for some special reason. The principles involved and the names used have been helpful in preparing this classification. Such classifications may be found in the works of Gregory, Meinzer, Fuller, and Johnson, cited in this paper, and in those of Hill and Vaughan,[3] Fournier,[4] and Kilian.[5] References to many articles on springs will be found in Meinzer's bibliography of ground water.[6]

The essential factors in the production of springs are the source of the water and the rock structure which brings it to the surface,

[1] M. l'Abbé Paramelle, *L'art de decouvrir les sources*, 4th ed. (Paris, 1896), chap. xi, pp. 64 ff.

[2] K. Keilhack, *Lehrbuch der Grundwasser und Quellenkunde*, Berlin, 1912.

[3] R. T. Hill and T. W. Vaughan, "Geology of Portions of the Edwards Plateau and Rio Grande Plain Adjacent to Austin and San Antonio, Texas," etc., *U.S. Geological Survey, Eighteenth Annual Report*, Part II *b*.

[4] M. E. Fournier, "Etude sur les sources, les resurgences et les nappes aquiferes du Jura Franc Comtois," *Bull. des Services de la Carte Géol. de la France*, etc. Tome XIII (1901–2), No. 89, pp. 1–55, with 31 figs.

M. E. Fournier, "Etudes sur les projets d'alimentation, le captage, la recherche et la protection des eaux potables," *Bull. des Services de la Carte Géol. de la France*, etc. Tome XIV (1902–3), No. 94, pp. 1–30, 1 fig.

[5] W. Kilian, "Essai d'une monographie hydrologique des environs de Gareoult (Var)," *Bull. de Services de la Carte Géol. de la France*, etc. Tome XVI (1904–5), No. 111, pp. 1–9 with 4 plates.

[6] O. E. Meinzer, "Bibliography and Index of the Publications of the United States Geological Survey Relating to Ground Water," *U.S. Geological Survey, Water-Supply Paper 427*, 1918.

and on these factors the classification outlined in this paper has been based. Temperature, dissolved salts, contained gases, rate and amount of flow, form and position of the spring opening are all characteristics of springs, which, while in many cases related to genesis, vary among springs of the same origin. It has seemed best to first divide springs into two groups based on character of the water and make further subdivisions on structural grounds.

In the use of this classification difficulties will arise which are of two types. In the first place, the local structure in the vicinity of springs is difficult to determine, for the presence and passage of water facilitates weathering and destroys the evidence. The presence of luxuriant vegetation also tends to conceal the structure. Whatever the difficulties of determining the structural relations and origin of the water for single springs, the study of groups of springs will usually be successful. The second difficulty arises through various combinations of structures which may combine to produce a spring. The structure which plays the predominating rôle should then determine the classification of the spring. The common sense and judgment of the investigator will lead him to the proper decision, but his labor will be easier if he remembers that ground water moves through three dimensions, though our conventional methods of illustration show but two. Springs of diverse origin may, however, have peculiarities so remarkable or interesting as to justify their grouping under a common name. The proposed system is not intended to supplant the use of such descriptive terms as blowing springs and thermal springs, but to provide a series of terms expressive of genesis which will include all springs, particularly those now called, for want of a better term, "common springs."

ACKNOWLEDGMENTS

In preparing this paper the writer has profited by the kindly criticism of members of the Ground-Water Club of Washington, D.C. The late Professor Joseph Barrell and Professor Herbert E. Gregory offered helpful suggestions. The writer wishes to acknowledge his special obligations to Dr. Henry Hollister Robinson for his generous help in methods of expression.

DEFINITION OF THE TERM "SPRING"

A spring is a place where water issues from the ground and flows or where it lies in pools that are continually replenished from below, except that wholly artificial openings, such as artesian wells, are not regarded as springs. Many springs have been modified by structures intended to increase their usefulness to man. A seep is a variety of spring in which the water comes, not from any definite opening, but through the pores of the ground over a considerable area. The amount of water yielded by most seeps is small. Many marshes and swamps are actually seeps on a large scale. Large ponds or lakes that are supplied with water through openings in their beds are called spring-fed lakes. A series of seeps and springs may occur along a line, which is then called a spring line. Many local names are used for springs, such as "water hole," "ciénega," and, in New Mexico, "ojo." Names like American Water, Bennet's Wells, Coyote Holes, and Ojo de Gato applied to springs show characteristic usage in the arid Southwest.

The conditions and processes that give rise to springs should be distinguished from those that bring about capillary discharge of ground water. The water of springs and seeps rises under pressure transmitted through the water as it lies as a continuous body in the voids of the rock. On the other hand, capillary discharge is due to molecular attraction between the soil particles and the water, acting against gravity. It takes place because the water is raised from the water table through minute openings in the soil by the force of capillarity and evaporates at or near the land surface. No water is released except by evaporation into the air, whereas the water of springs and seeps forms streams and pools unless the quantity is small and the evaporation excessive. The limit of depth to the water table necessary for capillary discharge to be effective is dependent on the size and uniformity of the soil grains. The limit of capillary rise for most soil is not over ten feet. Many areas that fulfil these conditions are large and well defined—for example, the alkaline flats of arid basins.

CHARACTERISTICS OF SPRINGS

In addition to the rate of flow, other characteristics or peculiarities of springs have given rise to names and classes. None of

these systems of classification are complete enough to include all springs, nor are the classes established even mutually exclusive. The names record only the peculiarities of springs, though these peculiarities may and many of them do arise from diverse causes.

Mineral springs are those which yield water containing in solution (1) unusual amounts of mineral matter, or (2) some uncommon or especially noticeable mineral matter. In distinction other springs are called "common springs." Ground water takes up soluble substances from the rocks through which it flows. In consequence small quantities of soluble matter near the point of emergence of spring water are very effective in changing its composition. Thus mineral content is at best an uncertain guide to the origin of the water or the cause of the spring. Usage also is not consistent. Many "mineral springs" yield water of a type that is common in adjacent regions, but because it is unusual in the immediate neighborhood they are distinguished from "common springs." If the water has or is supposed to have therapeutic value, "mineral springs" are often called "medicinal." Mineral springs are classed according to the chemical composition of the water, and one of the most elaborate classifications is that of Peale.[1]

Some of the simpler and more generally used terms are self-explanatory. Saline springs contain common salt; sulphur springs contain compounds of sulphur, usually hydrogen sulphide; chalybeate springs contain iron; calcareous or lime springs contain calcium carbonate; gypsum or "gyp" springs, gypsum; borax springs, borax, etc. Oil springs contain petroleum suspended in drops in the water. The drops of oil usually rise and form a thin iridescent film on the surface of the water. Inflammable gas may accompany the oil or may occur alone in spring water. Such spring waters have risen through or near beds containing petroleum or natural gas. False oil springs also occur. The iridescent film in these springs is due to iron hydroxide, which at one stage in its formation produces the film. In some springs an oily scum is produced by the decomposition of plants or animals buried but a few inches or feet below the spring opening.

[1] A. C. Peale, "The Natural Mineral Waters of the United States," *U.S. Geol. Survey, Fourteenth Annual Report* (1894), Part II, p. 66.

Springs may be divided according to temperature into thermal and non-thermal springs. Most non-thermal springs have temperatures that are approximately the same as the mean annual temperature of the air of the region in which they are found. The division between thermal and non-thermal waters is usually fixed at 70° F., but 20° to 25° above the mean for the region might be preferable. Thermal springs are usually called "hot," but those of slightly lower temperature are sometimes called "warm." Cold springs have temperatures below normal. The water of some cold springs is derived from the melting of ice or snow; that of others, being quickly transferred from a higher to a lower elevation through open channels, retains the temperature of its point of origin on emergence.

Boiling springs have a sandy bottom, through which the water emerges with some force. The sand is constantly agitated and appears to boil. Bubbling springs, also called boiling springs, are due to the emission of gas or vapor with the water. Certain hot springs actually boil in the ordinary sense. Usually emission of air or gases gives the impression of ebullition. Carbonated springs, which emit carbon dioxide, are the most common bubbling springs. Nitrogen, hydrogen sulphide, sulphur dioxide, marsh gas, and other gases have been found in spring waters. Bubbling is produced also by the emergence of water from a well-defined opening under considerable pressure into a pool of water. The surface of the water is domed, and slight fluctuations in volume or pressure give a bubbling effect.

Perennial or permanent springs flow throughout the year. Intermittent or temporary springs flow only during or after rain. Where evaporation is high the flow of springs is much decreased or may cease during the warm season. Some springs flow only at night because of a very delicate adjustment between supply of water and evaporation. Periodic springs flow at full strength for long or short periods, which are not closely related to the fluctuations in rainfall. The periodic action is dependent on the existence of open cavities. Springs here classed as solution tubular or cavern springs are most likely to have this characteristic. A cavity is drained by a small but insufficient outlet. As water

accumulates it may finally overflow through some higher opening and give rise to a periodic spring. Extreme periodicity of flow however, is attained only when the exit tube acts as a siphon so as to drain rapidly the water that has accumulated in the cavity during a considerable time.

Geysers are hot springs which at regular or irregular intervals emit a stream of mingled steam and hot water. The vent from which eruption takes place usually lies at the bottom of a pool of clear water, situated at the top of a conical mound of siliceous sinter. The sinter is deposited from the water in successive sheets of gelatinous silica, through the aid of living algae.

The geyser consists of a tube of hot water extending into the ground. The temperature of the water at the surface is about 212° F., but that of the water below the surface exceeds the normal boiling-point of water. The water in the lower part of the tube is prevented from boiling by the pressure of the overlying column. When the temperature at any point in the tube exceeds the boiling point for that depth, steam is formed. The expansion and rise of steam bubbles cause the water to overflow at the top. The consequent relief of pressure throughout the column of water causes instantaneous formation of steam from the superheated water. The result is an eruption. Of the water thrown out, part is lost and part returns to the tube. The next eruption occurs after the accumulation of sufficient water and an adequate rise in temperature.[1]

The three known geyser regions of the world are in New Zealand, Iceland, and Yellowstone Park, in each of which the geysers are associated with active or relatively recent volcanism. The heat may be attributed with certainty to still uncooled igneous rock. The water, however, may have either a deep-seated or a shallow origin.[2] Geyser action is not dependent on the origin of the water but on the existence of proper channels and the requisite temperatures. It seems likely that the presence of silica in solution is

[1] Bunsen and Descloiseaux, *Compt. Rend.*, XXIII (1846), 934, and other papers quoted by Archibald Geikie, *Textbook of Geology* (New York, 1902), p. 405; also W. H. Hobbs, *Earth Features and Their Meaning* (New York, 1912), p. 193.

[2] Arnold Hague, "The Origin of the Thermal Springs in the Yellowstone National Park," *Geol. Soc. America Bull.*, XXII (1911), 103–22.

essential to the formation of the tubes. Certainly the waters of all known geysers carry silica in solution in relatively large amounts.[1]

Ebbing and flowing springs occur along the seacoast. During high tide the sea water acts as a dam for the ground water and causes it to flow inland and at higher levels as springs. At low tide the ground-water level falls and the springs are reduced in volume or dry up. On this account the flow of springs adjacent to the shore fluctuates with the tide and may even cease at low tide except close to the shore, where some springs flow only at low tide. Rise and fall of water level due to the same cause have been noticed in wells.[2]

Blowing or breathing springs and wells are characterized by the emission of air, often accompanied by a trumpeting sound. They appear to be due to two causes: (1) rise of the water table, which causes the expulsion of air from cracks and pores of the rock;[3] (2) decrease in barometric pressure, which causes a similar movement.[4] The rise of water brings about blowing at relatively long and irregular intervals, but low air pressure recurs in short cycles.

Mound and knoll springs occur in arid climates. The water emerges at or near the top of a mound which has been built up by the accumulation of wind-blown sand and dust in the belt of vegetation surrounding the spring. The height of the mound is limited by the height to which the water can rise, for any accumulation of sand that is not moist is easily removed because it cannot support the protective vegetation. When the water can rise no higher, the process which builds the mound tends to ceil it over. If the water then finds a new and lower outlet, the mound is drained and subjected to erosion, especially by wind. Mound

[1] F. W. Clarke, "The Data of Geochemistry," 3d ed., *U.S. Geol. Survey, Bull. 616* (1916), p. 196.

[2] A. C. Veatch, "Fluctuations of the Water Level in Wells, with Special Reference to Long Island, N. Y.," *U.S. Geol. Survey, Water-Supply Paper 155* (1906), pp. 10 ff., 63–69. H. B. Woodward, *The Geology of Water Supply* (London, 1910), p. 90.

[3] H. B. Woodward, *op. cit.*, pp. 87–88.

[4] A. Strahan, "The Movement of Air in Fissures and the Barometer," *Nature*, Feb. 15, 1883, p. 375, quoted by Woodward. A. C. Veatch, *op. cit.;* C. W. Hall, O. E. Meinzer, and M. L. Fuller, "Geology and Underground Waters of Southern Minnesota," *U.S. Geol. Survey, Water-Supply Paper 256* (1911), p. 90.

springs are found in many arid countries in places where water emerges under pressure. Good examples occur in the Tularosa Basin in New Mexico.[1]

Pool springs have large, deep orifices filled with clear water. The pool is surrounded and partly covered with a shelf of fine earth supported by a network of vegetable fibers. The shelf is formed, like mounds, by the growth of vegetation and the filling of the ensuing tangle with wind-blown sand and dust. The two types occur in adjacent springs of the Fish Springs region, Utah, as described by Meinzer.[2] (See also p. 535 and Fig. 3.)

Many springs deposit around their mouths mineral matter that is carried in solution by the water. Calcium carbonate and silica are the most common minerals of spring deposits. Mounds, platforms, and ridges of considerable size are thus formed.

Mud volcanoes—low conical mounds having a crater at the top through which the water rises—are built up when water containing clay or fine sand rises to the surface under pressure. As the water spreads out of the vent it loses velocity and therefore deposits the matter it had carried in suspension. Such deposits are made by the temporary springs formed along fissures in unconsolidated rocks during earthquakes.[3] The emission of volcanic steam and gas through beds of tuff produces the same topographic form. "Salses," "air volcanoes," and "macculutos" are names applied to such springs in different parts of the world. In many of these springs the gases appear to be due to chemical changes in the earth, rather than to volcanism.[4]

SPRING WATER

The waters which circulate in the ground may be roughly divided into two types: (1) deep-seated waters, and (2) shallow waters. The shallow waters are derived largely from precipitation

[1] O. E. Meinzer, "Geology and Water Resources of Tularosa Basin, New Mexico, *U.S. Geol. Survey, Water-Supply Paper 343* (1915), p. 52.

[2] O. E. Meinzer, "Ground Water in Juab, Millard, and Iron Counties, Utah, *U.S. Geol. Survey, Water-Supply Paper 277* (1911), pp. 44–45.

[3] C. E. Dutton, "The Charleston Earthquake of August 31, 1886," *U.S. Geol. Survey, Ninth Annual Report* (1889), pp. 28–284, Plate XX.

[4] Archibald Geikie, *Textbook of Geology* (New York, 1902), p. 407.

at the surface and move through openings, which are generally supercapillary in size. Their movement is due to gravitative pressure transmitted through a continuous body of water, lying in the pore spaces and fractures of the rocks, i.e., by hydrostatic head. Since both kinds of openings decrease rapidly in number and size below 1,500 feet, these waters are limited in amount below that depth. Deep-seated waters have a complex origin. They doubtless include water derived by absorption from the surface, water entrapped in sedimentary rocks at the time of their deposition, and water expelled during the crystallization of igneous rocks. It is believed that these waters do not move because of hydrostatic head, that is, that they are not connected with any overlying and connecting body of water, but that flow is the result of other agencies operative deep within the earth.

Evidence that a spring water has a deep origin may be positive or negative. Thus the water of a spring that has a strong uniform flow not subject to seasonal changes and a high temperature probably has a deep-seated origin. The minimum depth from which the water may come can be roughly estimated from the temperature of the water, on the assumption that there is 1° F. increase in temperature for every 60 to 100 feet of increase in depth. In volcanic regions, however, the increase may be more rapid.

The presence of important breaks in the earth's crust or of other structures along which water could rise furnishes additional positive evidence. Negative evidence is usually easier to obtain and consists of the absence of any structure which could lead the water from the surface to the necessary depth and then return the water again to the surface.

CLASSIFICATION

I. SPRINGS DUE TO DEEP-SEATED WATER

Springs due to deep-seated water may be divided into two classes, according to their geographic distribution, with respect to localities of volcanic or tectonic disturbance. Their relations to the structure of the upper part of the earth's crust and the probable character of the fissures in the zones of fracture which permit the water to rise are shown diagrammatically in Figure 1. In this

figure, no attempt has been made to show the complicated and closely spaced fractures of the upper part of the crust. Only persistent fissures reach the surface, the others merge into the maze of minor fractures and joints.

Volcanic springs are associated with present or past volcanism. This direct association implies that they have their origin either in water expelled from the underlying magma or in surface water that has come into contact with highly heated rocks and has acquired definite characteristics from this association. In general such springs have strong and relatively constant flows and are highly

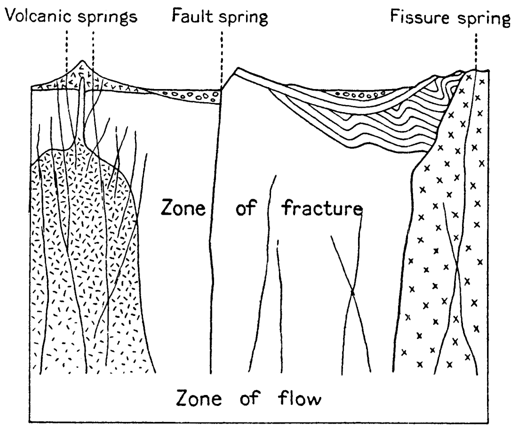

FIG. 1.—Diagram illustrating springs due to deep-seated water

mineralized, and many are gaseous. Some of them have very high temperatures and cannot be sharply divided from volcanic vents emitting steam and gases—fumaroles, solfataras, and mofettes. Others have relatively low temperatures, and many contain carbon dioxide gas. It is generally difficult or impossible to distinguish the latter from springs of non-volcanic origin. The peculiar phenomenon called geyser action characterizes some hot volcanic springs. A typical group of volcanic springs without geyser action lie on the south flank of Lassen Peak, in California (Fig. 2).

The other group of springs due to deep-seated water may be termed fissure springs. In general they have a strong and constant

flow, not subject to annual fluctuations. They are usually warm or hot, and many are highly mineralized. They appear to rise along deep fractures extending far into the crust of the earth. The fractures are similar to those in which were formed the veins now found in mining operations. Doubtless the waters that deposited veins in many places reached the surface as springs.

Certain fissure springs lie along definite lines, and these lines are known to be recent faults involving earth blocks of great depth.

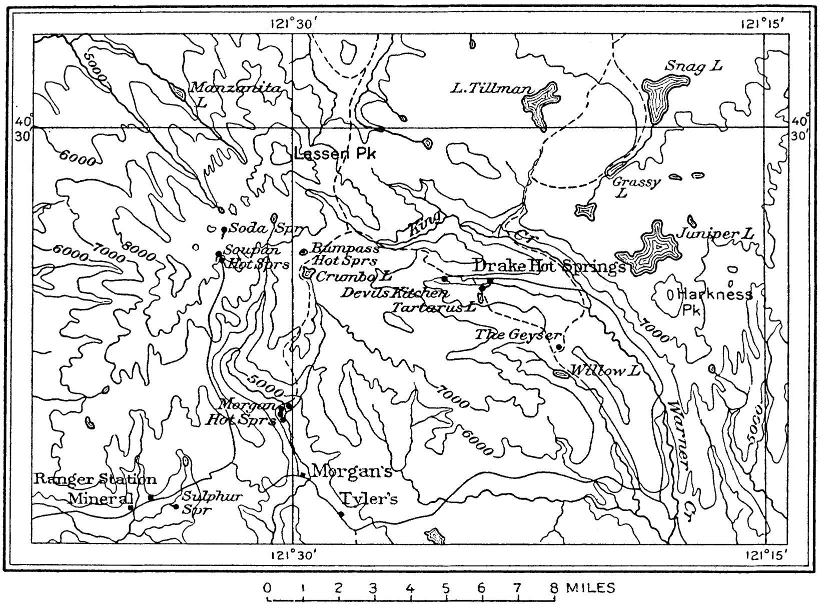

FIG. 2.—Sketch map of Lassen Peak region, California

Faulting appears to produce the fractures which allow these deep waters to rise and carry the temperatures of the deeper crust to the surface. Such springs may be called fault springs. The thermal springs east of the Fish Springs Range, in Juab County, Utah, are a classic example of springs of this type (Fig. 3). The Fish Springs Range is the result of block faulting. The range has a distinct tilt to the west and the fault runs along the eastern flank. Very recent faulting is shown by a fresh fault scarp in the alluvium

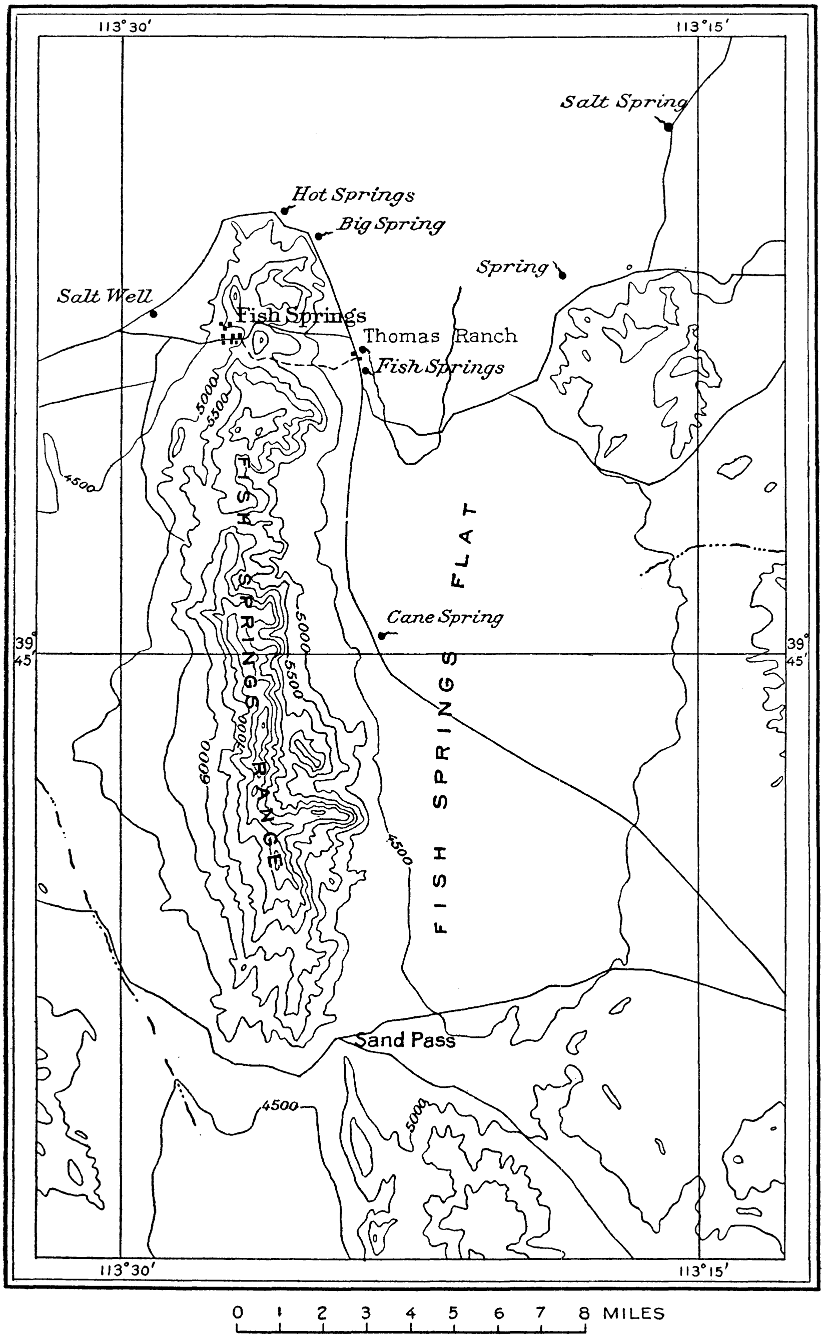

FIG. 3.—Sketch map of Fish Springs Range, Utah

near Fish Springs.[1] Four groups of springs lie east of the range. Hot Springs, Big Springs, and the Fish Springs are on a curving line close to the mountains. They have a steady flow of somewhat mineralized water, and their temperatures are between 78° and 104° F. Cane Spring lies 7 miles south of the Fish Springs group, at the base of the alluvial slope. It consists of a number of seeps of highly mineralized water. Up the slope to the west is the Devil's Hole, a pool of water about 10 or 15 feet below the surface. The form of the pool is similar to those of the Fish Springs group.[2]

Hot Springs, Big Spring, and the Fish Springs are too close to the mountain front to receive much water from the alluvium. Their steady flow and mineralized water imply a deep-seated source, and the recent fault with which they are associated is quite certainly the channel along which they rise. The Cane Spring has the situation of ordinary border springs, but the character of its mineralization and its large volume suggests that part of the water is derived from the now buried southern extension of the same fault. The Devil's Hole may be the last survivor of a group of fault springs whose water has been diverted into the alluvium and rises along the edge of the flat in Cane Spring.

On the other hand, there are fissure springs for whose origin there is no structural evidence. They are believed to have a deep origin because they are not associated with any surface structure that would warrant so strong a flow of water and because of their heated or mineralized condition. Of 98 groups of hot springs in California, 36 occur in granitic rocks.[3] Some of these are fault springs, but others are not directly associated with known faults and can be accounted for only on the supposition that they rise along open fractures or fissures that extend into and draw water from the deeper parts of the earth's crust.

[1] G. K. Gilbert, "Lake Bonneville," *U.S. Geol. Survey, Monograph I* (1890), p. 353.

[2] O. E. Meinzer, "Ground Water in Juab, Millard, and Iron Counties, Utah," *U.S. Geol. Survey, Water-Supply Paper 277* (1911), pp. 43–45, 124–26.

[3] G. A. Waring, "Springs of California," *U.S. Geol. Survey, Water-Supply Paper 338* (1915), p. 154.

II. SPRINGS DUE TO SHALLOW WATER

The pore spaces of the upper crust of the earth are filled with water below a certain level called the water table. This zone of saturation generally has an indefinite extension downward, but in relatively few deep wells is much water encountered below 1,500 feet. Springs due to these relatively shallow waters may be divided into four large groups, according to the character of the rock in which they occur: (1) springs in porous rock; (2) springs in porous rock overlying impervious rock; (3) springs in porous rock between impervious rock; (4) springs in impervious rock.

A. SPRINGS IN POROUS ROCK (DEPRESSION SPRINGS)

Springs in porous rock are formed where the water table or upper surface of the zone of saturation reaches the surface of the ground. Because they are due to the depression of the land surface down to or below the water table, the group may be called depression springs. They are springs whose flow is rather gentle or pools of water that are continually replenished from below. Many are seeps or, if extensive, swamps. They may be divided according to topographic position into four classes, as described in the following paragraphs:

Dimple springs are due to depressions in hillsides which permit the land surface to cut the water table (Fig. 4 *a*). Such depressions or dimples in a sloping surface may arise through erosion by water or wind, through slumping and landslides, through the overturning of trees, or through the operations of burrowing animals, and many are enlarged and deepened by the trampling of larger animals.

Valley springs are due to the abrupt change in slope at the line between the bounding valley walls and the edge of a flood plain (Fig. 4 *b*). Along this line the water table may reach the surface and form seeps or springs. Gullies or low spots between adjacent small alluvial fans may determine the point of emergence. Various causes may enlarge these depressions or may concentrate the flow of the water at specific places, as in the dimple springs.

Channel springs are due to depressions in flood plains or alluvial plains caused by the channel cutting of streams (Fig. 4 *c*). They

thus include all sorts of side channels, abandoned channels, oxbow lakes, sloughs, and water holes. Springs of this type are exceedingly valuable in arid regions. They are frequently made, destroyed, and remade by streams that carry large quantities of sediment.

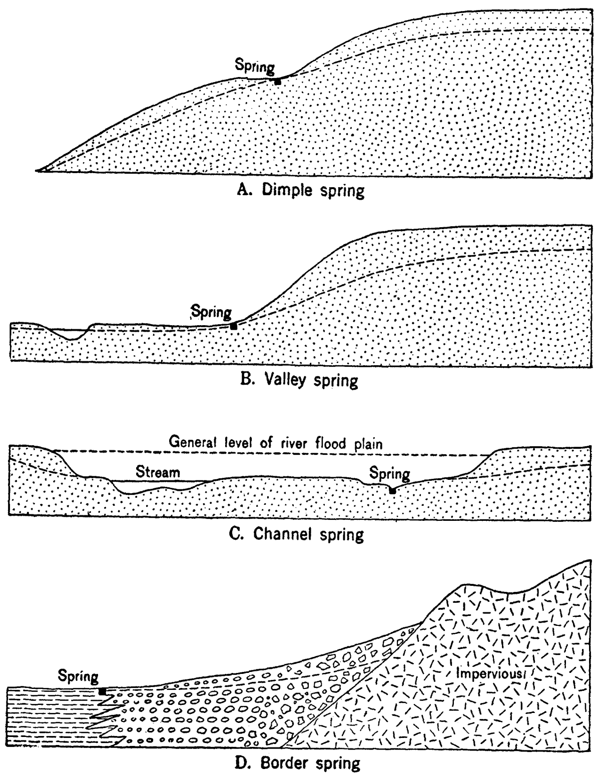

FIG. 4.—Diagram illustrating four classes of depression springs: *a*, dimple springs; *b*, valley springs; *c*, channel springs; *d*, border springs.

Border springs are due to the change in gradient at the line between the alluvial slopes and central flat of a desert basin (Fig. 4 *d*). Such alluvial slopes extend from the mountains with a gradually decreasing gradient. This decreasing slope finally merges with a central undrained flat or with the river bottom of a through-flowing stream. Around the edges of such a flat or the river bottom of a through-flowing stream is a line of springs and seeps.

Ground water is brought to the surface primarily by the change in slope, but the dense silts and clays of the center of the basin tend to act as a dam to prevent further movement down the slope. Thus by their presence they assist the water to rise and may determine the exact location of certain springs. Such border springs are common in the intermontane valleys or bolsons of the western United States. Those of the Big Smoky Valley, Nevada, are shown in Figure 5 and have been described[1] as follows:

> The main west-side spring line of the upper valley extends, with a sinuous course due to the different sizes of alluvial fans, from the Vigus ranch to Wood's ranch, a distance of more than 30 miles, and includes innumerable springs that discharge a part of the copious underground supply received from the Toyabe Range. On the east side of the upper valley there is no spring line comparable to that on the west side, probably because the supply from the Toquima Range is smaller than that from the Toyabe Range, but numerous springs similar to those on the west side are found for a distance of 3 miles in the vicinity of the Charnock ranch.

Concerning the Darrough Hot Springs, which lie along this same line, Meinzer[2] says:

> The water issues from bowldery fill, but probably comes originally from the underlying rock, the heat being due either to igneous intrusion or to faulting that opened deep fissures, or to both causes. Less than 100 feet from the main hot spring and at a level a few feet higher there is a small spring that issues at a temperature of only 60° F., which is almost the normal temperature for this region.

B. SPRINGS IN POROUS ROCK OVERLYING IMPERVIOUS ROCK (CONTACT SPRINGS)

Where porous rock overlies impervious material the water that accumulates in the porous rock is forced to the surface at the contact. Springs so formed may therefore be called contact springs. The form and attitude of the surface of the underlying impervious material divides them into three general types. In one the surface is regular and horizontal, in another the surface is regular but inclined, and in the third the surface is irregular.

[1] O. E. Meinzer, "Geology and Water Resources of Big Smoky, Clayton, and Alkali Spring Valleys, Nevada," *U.S. Geol. Survey, Water-Supply Paper 423* (1917), pp. 86, 87, Plate II.

[2] *Ibid.*, p. 89.

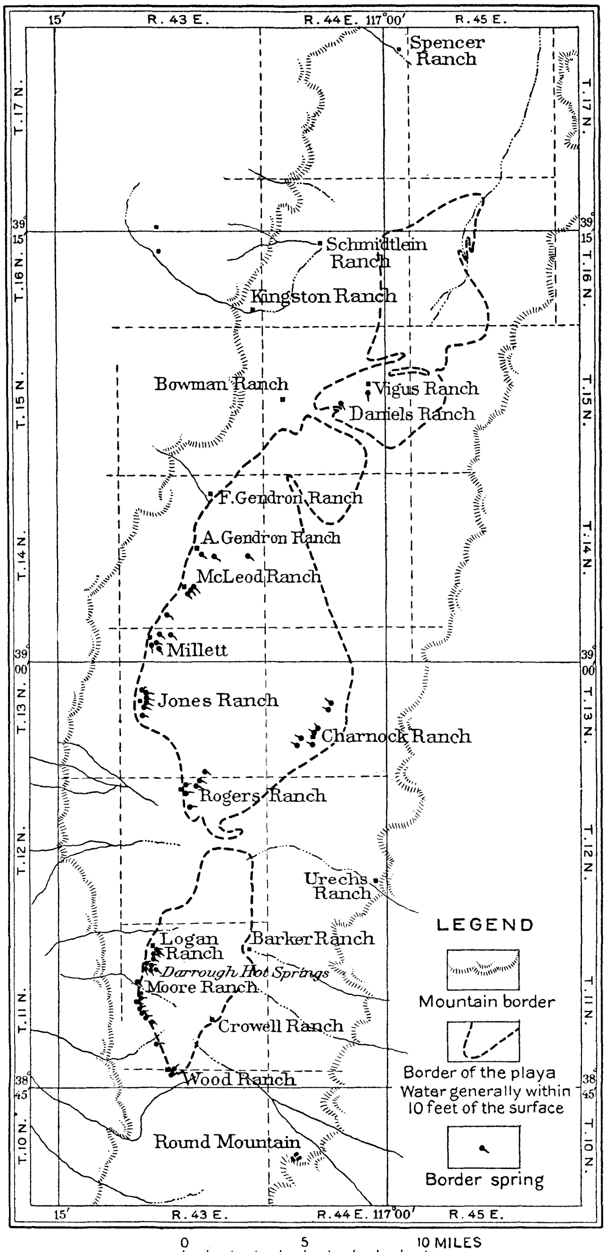

FIG. 5.—Map of the upper Big Smoky Valley, Nevada, showing border springs. (After Meinzer.)

1. *Springs at the outcrop of a horizontal surface.*—Where the impervious rock has a horizontal and regular surface of large extent the rock is usually a member of the sedimentary series of which the overlying porous material is a part. Exceptions, however, occur where the porous material is a surficial deposit but is so regular in its thickness as to give a similar result, or where it is of volcanic origin. There are three classes of these springs.

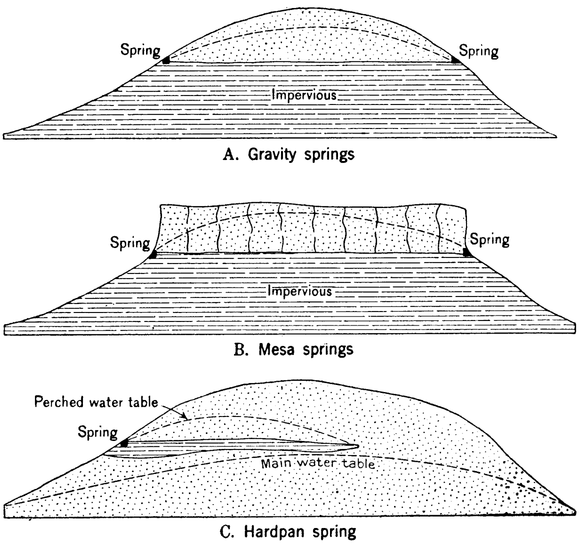

FIG. 6.—Diagram illustrating three classes of contact springs with underlying bed regular and horizontal: *a*, gravity springs; *b*, mesa springs; *c*, hardpan springs.

Gravity springs are those which issue at the contact of a soft and previous bed with an underlying impervious bed (Fig. 6 *a*). The term has been used by Fuller[1] and others. As all springs of the shallow-water type are due to gravity, this term has only the merit of usage. Good examples are Camp Grounds Spring, Crab Tree Spring, and others east of Austin, Arkansas. These springs occur around the edges of the sand-hill area, a ridge of Tertiary rocks on the border of the Mississippi embayment (Fig. 7). Here a thin

[1] M. L. Fuller, "Underground Waters for Farm Use," *U.S. Geol. Survey, Water-Supply Paper 255* (1910), p. 22.

sandstone and sandy clay overlie clay. Water that collects in the sandy beds emerges in a series of springs at the contact with the underlying clay, slightly above the level of the adjacent flood plain of the Mississippi.[1]

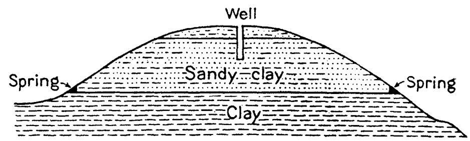

FIG. 7.—Cross-section from Austin to Hickory Plains, Arkansas, illustrating gravity springs. (After Purdue.)

Mesa springs are those due to an overlying material which is hard and forms a cliff (Fig. 6 *b*). In this class the overlying material is commonly a sandstone, though it may be a porous and jointed lava flow. Along the east side of Chuska Mountain, New Mexico, in the Navajo country, at an elevation of 8,200 feet, a rough-floored terrace extends for several miles (Fig. 8). Above the shale which floors the terrace a cliff of horizontal Chuska sandstone rises 200 to 500 feet. At the foot of the cliff are more than thirty springs.[2]

If the underlying bed is of small extent but impervious, it will force water contained in overlying porous material to the surface. In many places such water lies far above the ordinary water table and constitutes what is called a perched water table.[3] Such conditions are fairly common in unconsolidated alluvium. The impervious bed is usually clay, cemented gravel, a "mortar bed," or a layer of caliche or hardpan. As in popular usage all these materials are known as hardpan, springs caused by them may be called hardpan springs (Fig. 6 *c*). The older alluvium of the Sacramento Valley is generally underlain by a bed of reddish hardpan about two feet below the surface. During and after rains water seeps to the surface at the contact of the hardpan with the overlying soil, forming temporary springs. A few springs of this class

[1] A. H. Purdue, "Water Resources of the Contact Region between the Paleozoic and Mississippi Embayment Deposits in Northern Arkansas," *U.S. Geol. Survey, Water-Supply Paper 145* (1905), pp. 93, 113.

[2] H. E. Gregory, "The Navajo Country," *U.S. Geol. Survey, Water-Supply Paper 380* (1916), pp. 140–41.

[3] A. C. Veatch, "Underground Water Resources of Long Island, N.Y.," *U.S. Geol. Survey, Prof. Paper 44* (1906), p. 57.

near Corning, California, in places where the soil above the hardpan is thick and continuous enough to form a reservoir, are permanent.

2. *Springs at the outcrop of an inclined surface.*—If the underlying impervious bed has a regular but inclined surface, all the

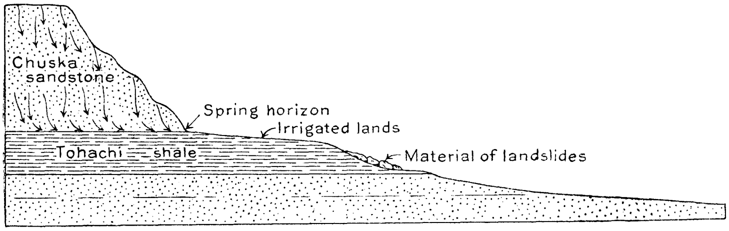

FIG. 8.—Diagram illustrating the conditions producing springs on the east flank of Chuska Mountain, New Mexico. (From Gregory.)

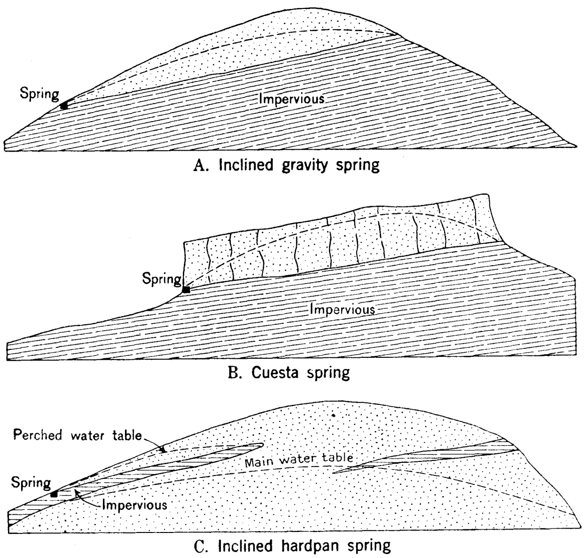

FIG. 9.—Diagram illustrating three classes of contact springs with underlying bed regular and inclined: *a*, inclined gravity springs; *b*, cuesta springs; *c*, inclined hardpan springs.

springs will occur at the outcrop of the contact on the low side, unless the overlying bed is very thick and the dip of the rocks slight. In general, where the underlying bed is of large extent, these conditions exist in sedimentary rocks. Springs of this kind are

divided into two classes, one in which the overlying material is soft and the other in which it is hard. Those of the first class may be called inclined gravity springs (Fig. 9 *a*) and those of the second cuesta springs, after the topographic feature analogous to a mesa (Fig. 9 *b*). Large springs of the inclined gravity type occur near Baden-Baden, Germany (Fig. 10). At this place the lower and middle Buntsandstein, both porous and water-bearing, rest on the smooth erosion surface of the granite. The sandstone has been tilted and eroded into isolated patches. Numerous springs issue along the contact of the sandstone and the granite on the lower side of these erosion remnants. A few springs occur in the talus slopes and on the higher contacts.[1]

Good examples of cuesta springs are those which arise at the contact of basaltic lava and shales of Tertiary age along the western flank of South Table Mountain, north of Oroville, California. The lava is sufficiently jointed and porous to collect water, which runs down the dip of the contact and emerges along the western and lower face of the cuesta.

If the underlying bed is of small extent, springs can only occur where the impervious layer dips with the slope of the hillside but at a smaller angle. These springs are essentially like those in which the impervious layer is horizontal and may also be called hardpan springs (Fig. 9 *c*). The Mountain Mist Springs, in the West Hills, along the northern shore of Long Island (Fig. 11), are of this class. The underlying hardpan is a compact till, and the perched water table lies about 200 feet above the main water table.[2]

3. *Springs at the outcrop of an irregular surface.*—Where the underlying impervious bed has an irregular surface, the overlying material is commonly thin and unconsolidated—a mantle overlying the bed rock. In humid countries the great majority of springs are formed by water that collects in the reservoirs afforded by this porous material. It varies in thickness and character and the irregularities of the underlying surface originate in diverse ways.

[1] H. Eck, "Geognostische Beschreibung der Gegend von Baden-Baden, Rothenfels, Gernsbach, und Herrenalb," *K.-preuss. geol. Landesanstalt Abh.*, neue Folge, Heft 6 (1892), pp. 653 ff.

[2] A. C. Veatch, "Underground Water Resources of Long Island, N.Y.," *U.S. Geol. Survey, Prof. Paper 44* (1906), pp. 57–58.

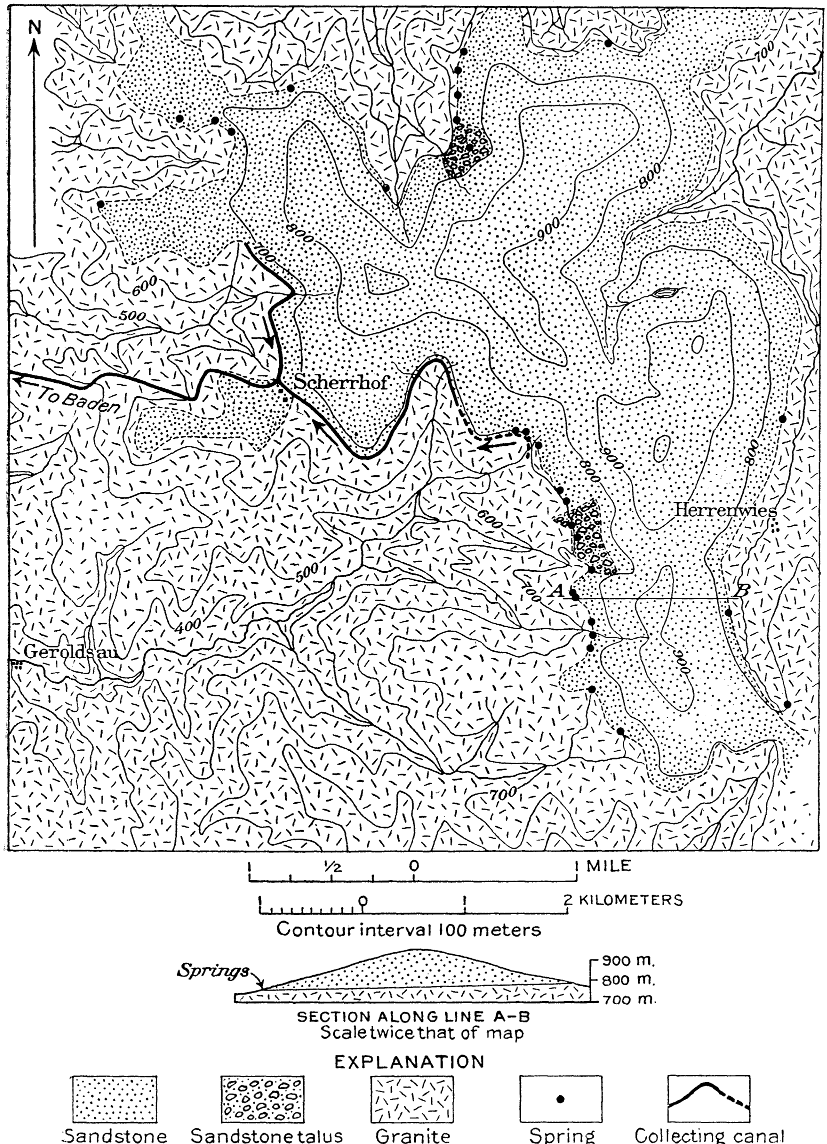

FIG. 10.—Map of an area near Baden-Baden, Germany, showing inclined gravity springs, and connecting canal fed by inclined gravity springs. (Redrawn from Keilhack, after Eck and Lueger.)

Four classes of springs in this group are distinguished in the following paragraphs.

Where the overlying material is thick and of wide extent, the contact is ordinarily an unconformity. The irregularities of such a contact are of minor significance, and here all the types of springs included in the previous group—gravity, inclined gravity, cuesta, and mesa springs—may occur. The springs will be found at the

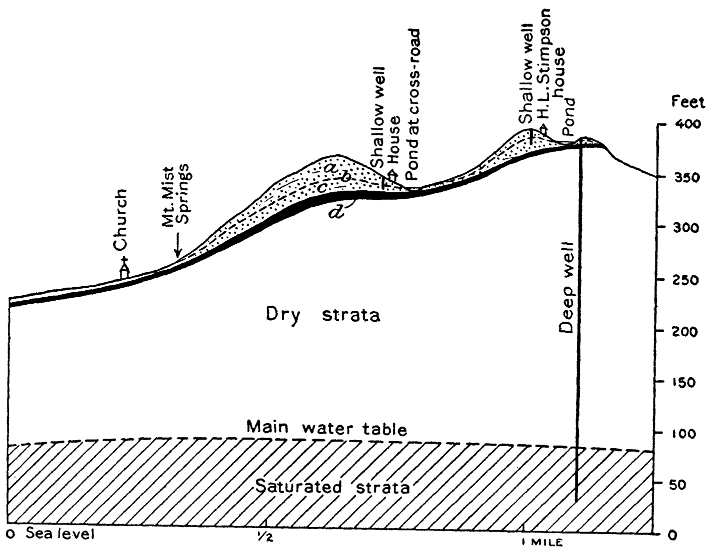

FIG. 11.—Cross-section showing inclined hardpan on the north side of the West Hills, Long Island, New York, and source of Mountain Mist Springs. (After Veatch.)

lowest parts of the contact. Mesa springs that fulfil these conditions occur at the Hopi Buttes, in Arizona (Fig. 12), where the overlying bed is a porous and jointed lava flow underlain by patches of volcanic ash and the underlying impervious beds are tilted and eroded shales and sandstones. The unconformity is fairly smooth, but springs issue in the lowest places.[1]

Where the overlying porous material is localized and the contact is irregular, the resulting springs may be called pocket springs, because the reservoir from which the water is drawn lies

[1] H. E. Gregory, *op. cit.*, p. 139.

in a pocket in the underlying rock (Fig. 13 *a*). The overlying material, which is usually unconsolidated and generally of relatively small volume, may be of different kinds, of which the most common are residual soil, alluvium, till, and wind-blown sand. This is the prevailing type of spring in the till-covered hills of New England and in the soil-covered crystalline rocks of the Sierra Nevada. Most small springs are grouped under this head.

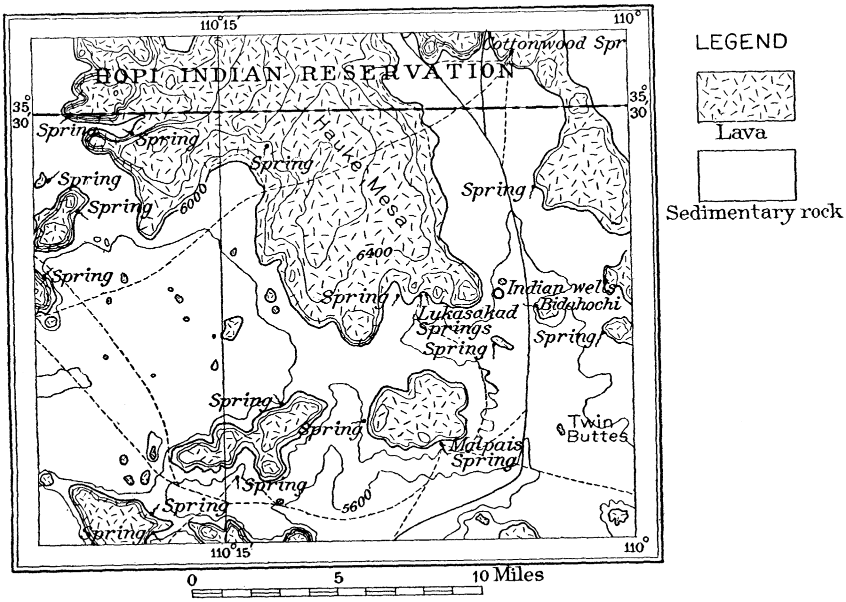

FIG. 12.—Map of a part of the Hopi Buttes, Arizona, showing distribution of mesa springs with reference to lava and sedimentary rock. (From Gregory.)

Pocket springs at the western border of Owens Valley, California, are described by C. H. Lee[1] as follows:

> The springs at the mouth of Sardine Canyon derive most of their supply from the run-off of the drainage area, which sinks into porous gravel deposits in the lower canyon. There is also contribution from accumulations of slide material on the mountain face at the mouth of the canyon. The flow from this group (three springs) varies from 3 to $1\frac{1}{2}$ second-feet.

[1] C. H. Lee, "An Intensive Study of the Water Resources of a Part of Owens Valley, California," *U.S. Geol. Survey, Water-Supply Paper 294* (1912), p. 44 and Plate XXV.

Overflow springs, like pocket springs, are due to the overflow of a reservoir of porous rock (Fig. 13 *b*). The underlying impervious bed is not continuous, but percolation through the porous bed is not sufficient to drain the reservoir. The reservoir is commonly large and of structural origin. These springs are most common in

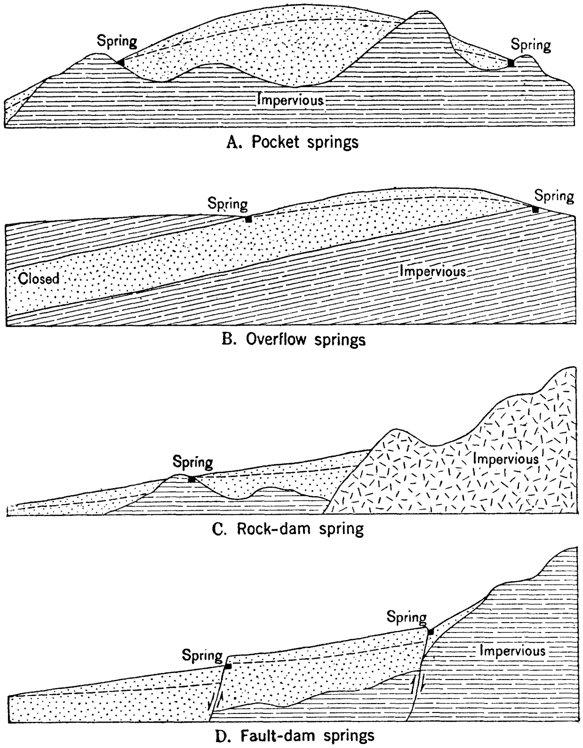

FIG. 13.—Diagram illustrating four classes of contact springs with underlying bed irregular: *a*, pocket springs; *b*, overflow springs; *c*, rock-dam springs; *d*, fault-dam springs.

the collecting area of an artesian system and are distributed along the contacts of the inclosing impervious rocks. An example is found in the North Downs, near London, England (Fig. 14). Many of the springs at this place have ceased to flow because of excessive pumping from wells in the artesian basin to the south.[1]

[1] H. B. Woodward, *The Geology of Water Supply* (London, 1910), pp. 133–35, Figs. 12, 34.

Similar masses of pervious rock may be bounded on one or more sides by impervious rock brought into place by faulting. Overflow will then take place among the fault line, as is exemplified in the northern Vosges Mountains, France[1] (Fig. 15).

In arid regions, particularly, great thicknesses of alluvium have accumulated on irregular rock floors, and if the irregularities of

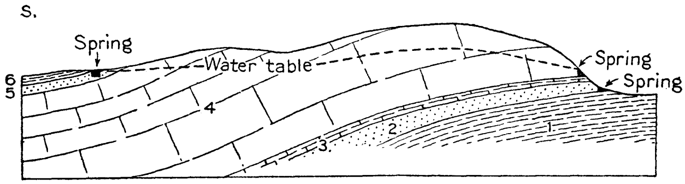

FIG. 14.—Cross-section of the North Downs, near London, England: 1, gault; 2, upper greensand; 3, chalk marl; 4, main chalk, pervious to water; 5, lower London Tertiary strata; 6, London clay, impervious to water. (Redrawn from Woodward.)

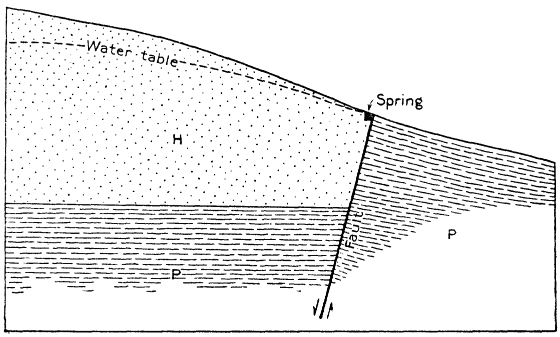

FIG. 15.—Cross-section showing overflow spring in the northern Vosges Mountains, France. H. Hauptbunt-sandstein (porous); P. Rötelschiefer (impervious). (After Leppla.)

the rock floor project through the surface of the alluvial plains, the water contained in the alluvium may be forced to the surface. Essentially similar conditions may be brought about by intrusion of igneous material into such alluvial plains. Under these conditions the rock projections act as dams against the regular flow of the ground water, and the resulting springs may be called rock

[1] A. Leppla, quoted by K. Keilhack, *Lehrbuch der Grundwasser und Quellenkunde*, Berlin, 1912.

dam springs (Fig. 13 *c*). The best-known examples are the ciénegas of the valleys of southern California. West of Cucamonga (Fig. 16) a projection of older cemented alluvium in the Red Hills

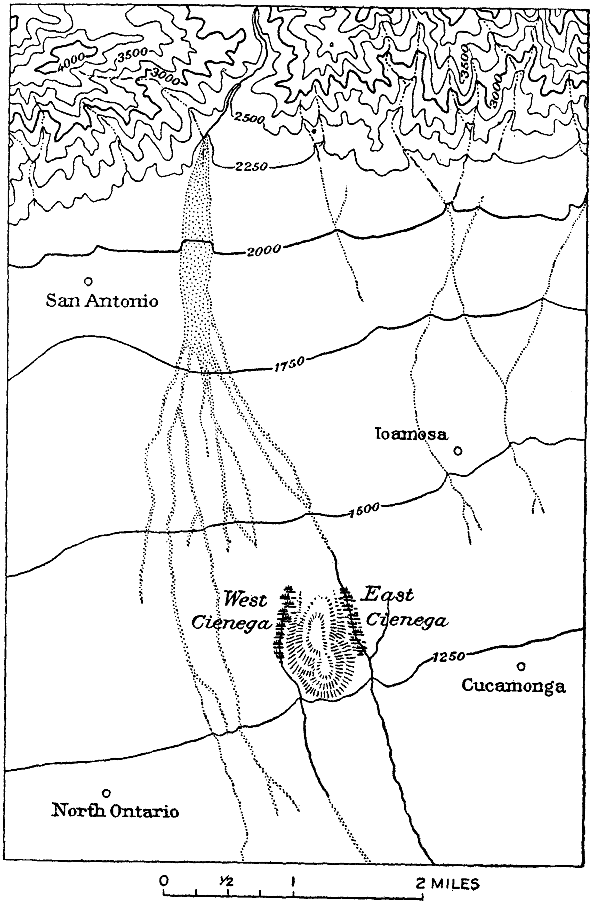

FIG. 16.—Map showing rock-dam springs near Cucamonga, California. (After Mendenhall.)

produces East and West ciénegas; a similar projection of the rocks of the San Rafael Hills produces the springs of Devil's Gate, north of Pasadena.[1] In the Antelope Valley a part of the rock floor of

[1] W. C. Mendenhall, "Ground Water and Irrigation Enterprises in the Foothill Belt, Southern California," *U.S. Geol. Survey, Water-Supply Paper 219* (1908), pp. 34–38, 50–53.

the basin rises above the alluvial plain and produces Lovejoy Springs.[1] Examples of rock dams formed by intrusion of igneous rock into alluvium have not yet been found.

Fault dam springs arise where the free flow of ground water through porous material is interfered with by faulting (Fig. 13 *d*). Fault zones become efficient barriers by the formation of gouge or simply through disturbance and dislocation of the beds. Examples

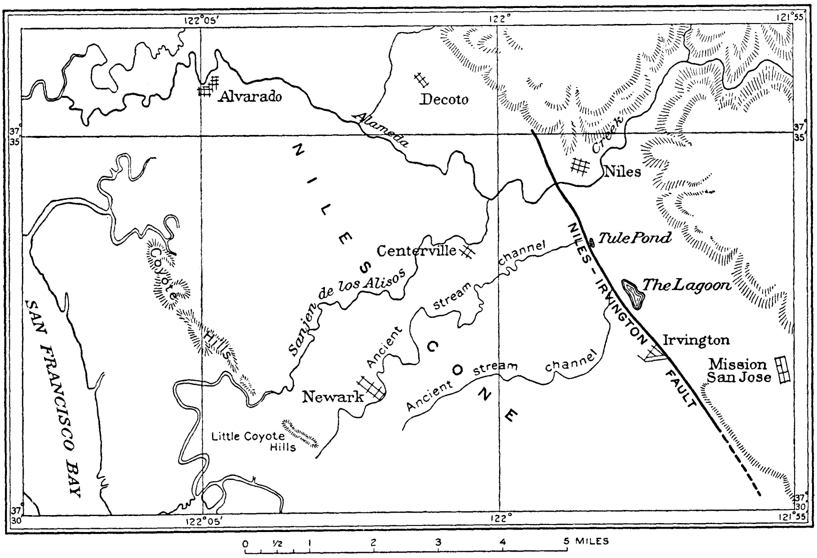

FIG. 17.—Map of the Niles cone, California, showing fault-dam springs due to the Niles-Irvington fault. (After Clark.)

of this class of spring have been found in the Big Smoky Valley, Nevada, by Meinzer.[2] The Niles-Irvington fault, in the Santa Clara Valley, California, beheads an alluvial fan (the Niles cone[3]), as shown in Figure 17. On the side near the mountains the water

[1] H. R. Johnson, "Water Resources of Antelope Valley, California," *U.S. Geol. Survey, Water-Supply Paper 278* (1911), p. 52, Fig. 9.

[2] O. E. Meinzer, "Geology and Water Resources of Big Smoky, Clayton, and Alkalai Spring Valleys, Nevada," *U.S. Geol. Survey, Water-Supply Paper 423* (1917), p. 90.

[3] W. O. Clarke, "Ground Water Resources of the Niles Cone and Adjacent Areas, California," *U.S. Geol. Survey, Water-Supply Paper 345* (1915), pp. 130–32, 150.

table is about 20 feet higher than on the downstream side. Two ponds fed by ground water lie east of the fault. They are fault dam springs.

C. SPRINGS IN POROUS ROCK BETWEEN IMPERVIOUS ROCK (ARTESIAN SPRINGS)

Where water is contained in the pore spaces of a pervious bed lying between impervious strata, the essential conditions for the

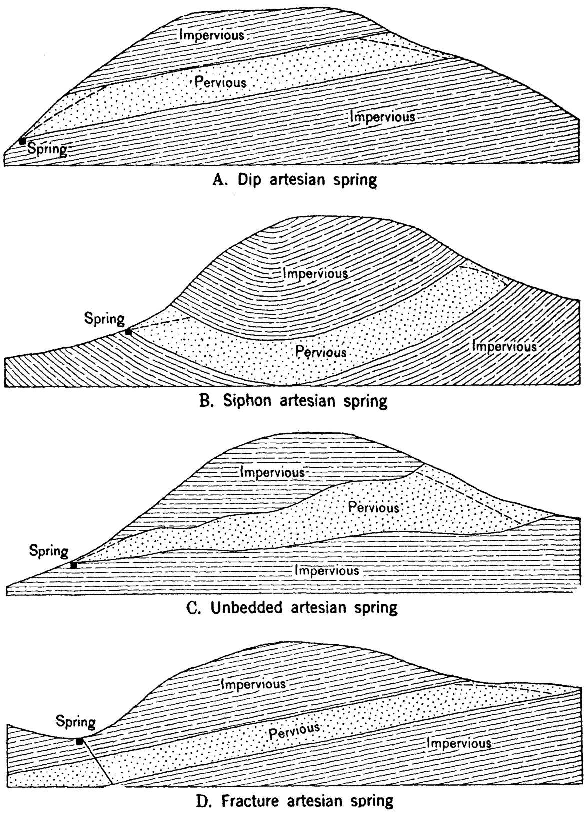

FIG. 18.—Diagrams illustrating four classes of artesian springs: *a*, dip artesian springs; *b*, siphon artesian springs; *c*, unbedded artesian springs; *d*, fracture artesian springs.

existence of springs are that a part of the porous bed outcrop so as to absorb rain in order to provide a regular supply of water, and that the beds be inclined—in other words, the essential conditions

are those of an artesian basin. There are four classes of springs which fulfil these conditions.

Dip artesian springs (Fig. 18 *a*) occur in more or less regularly bedded rocks that have been tilted and eroded in such a manner that the porous bed receives water from the rain or streams in its upper end and that the lower end is exposed at the surface. Sedimentary rocks, alternating lava flows, tuffs and gravels, and unconsolidated alluvial material supply these conditions.

In a series of beds that has been folded, if the proper conditions of inflow and outflow exist, a porous stratum constitutes an inverted siphon for the conveyance of water. Springs due to the outflow from the low side of such a basin may be called siphon artesian springs (Fig. 18 *b*). The artesian basin of the Great Plains is the

FIG. 19.—Cross-section of the Great Plains showing siphon artesian springs near Sioux City, Iowa. (After Darton.)

largest and most remarkable in the world, because of the great distance traveled by the water and the heavy pressure under which it exists. Along the eastern border of the basin the beds have a distinct westward tilt, but the water-bearing Dakota sandstone is not everywhere exposed (Fig. 19). However, near Sioux City, Iowa, numerous springs and seeps are found along the western bluffs of Missouri River, where the Dakota first emerges from beneath its impervious cover.[1]

In certain unconsolidated deposits not regularly bedded, a mass of porous material may be so exposed as to receive water at a high level and discharge this water at a lower level. The springs resulting from this structure may be called unbedded artesian

[1] G. E. Condra, "Geology and Water Resources of a Portion of the Missouri River Valley in Northeastern Nebraska," *U.S. Geol. Survey, Water-Supply Paper 215* (1908), pp. 27, 28.

springs (Fig. 18 *c*). Though rare, springs of this class occur in till, and doubtless examples may be found in other types of rock.

The springs of the three classes just described depend on the outcrop of the saturated porous bed in its lower portion. Springs occurring where the porous bed does not crop out, but the water escapes from it by an opening leading to the surface, may be termed fracture artesian springs (Fig. 18 *d*). Many of these springs have been classed with fissure springs, but it seems essential to distinguish between springs that tap artesian basins and yield water under hydrostatic head, and those that depend on the deeper waters of the crust. This name is chosen because it seems probable that all such openings are primarily fractures in the rocks. Although it is true that great pressure is exerted by the water in deep artesian basins, it seems improbable that pressure could force water to rise through overlying material in sufficiently definite channels to supply springs unless it moved along pre-existing faults or other fractures. Water pressure may assist in keeping the fracture open, and the flow of water tends to plaster up caving walls with mud, as in the hydraulic systems of drilling wells, or to solidify them with precipitated minerals. Many of the springs of this class have a high temperature, a steady flow, and an alignment that causes them to be confused with true fault springs. However, a distinction should be made. If definite artesian structure can be demonstrated, most of the water is probably meteoric in origin—that is, it is derived from rain or melted snow absorbed at the outcrop; if artesian structure cannot be demonstrated, there is a strong presumption that much of the water arising along great faults and deep fractures in the crust is of juvenile origin—that is, it issues from deep within the earth and now sees the light of day for the first time. At any rate, there is a sufficiently distinct difference in structure to justify separate classification of the springs.

In Antelope Valley, California, porous sand and gravel underlying clay contain water under artesian pressure. Numerous wells have been sunk to obtain this water, and its chemical character and temperature are known. Buckhorn, Indian, Willow, and other springs having water similar in character and temperature

lie along a fault at the foot of Rosamond Buttes but probably not exactly on the fault trace (Fig. 20). This fault is represented by an escarpment in the alluvium west of Willow Springs, from 50 to 100 feet in height and extending for a distance of 5 miles.[1] The

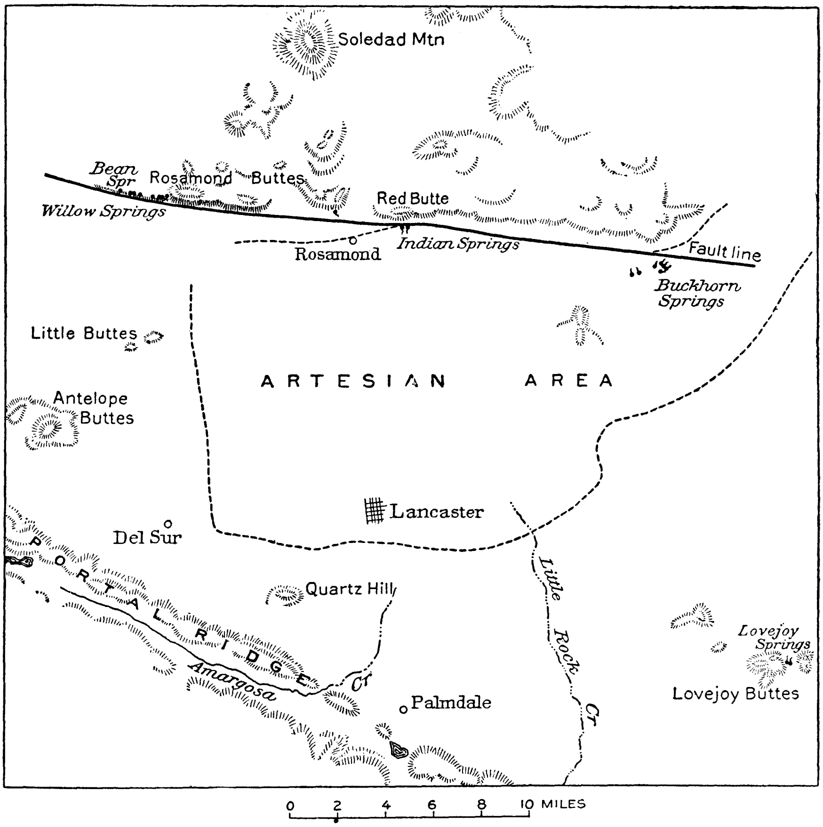

FIG. 20.—Map of Antelope Valley, California, showing fracture artesian springs. (After Johnson.)

irregular alignment of these springs is best explained by assuming that there are associated with the main fault a number of subsidiary but parallel fractures which permit the artesian water to rise. Alternative explanations are offered by Johnson, but the absence of springs except along this general line makes other

[1] H. R. Johnson, *op. cit.*, pp. 21 and 49.

explanations improbable. These springs, therefore, may be taken as typical of the class of fracture artesian springs.

D. SPRINGS IN IMPERVIOUS ROCK

The term porous and impervious are of course relative, but impervious rocks may be considered to have pore spaces of capillary or smaller size, which usually form a relatively small percentage of the rock. Some clay, however, has a high porosity but because of the absorption of water and swelling of individual grains is highly impervious. Through such pore spaces effective flow under hydrostatic head is impossible. Movement takes place

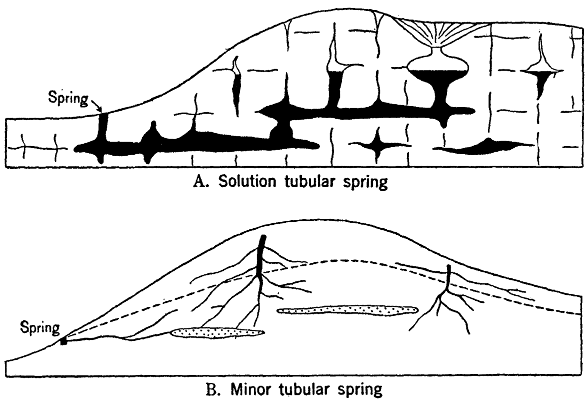

FIG. 21.—Diagram illustrating two classes of tubular springs: *a*, solution tubular springs; *b*, minor tubular springs.

through openings which may be grouped into two types: (1) those which are more or less tubular in form, and (2) those which are sheetlike in form and along which the water moves as a thin film.

1. *Tubular Springs.*—Springs of the first group may be called tubular springs. This group can in turn be divided into three classes, according to the origin of the tubular openings. Solution tubular or cavern springs are due to channels and openings formed through solution of the rock by circulating ground water (Fig. 21 *a*). Solution commonly begins along joints or other previously existing openings, and the channels may be enlarged to a very great size. In these tubes the water then flows freely and with relative rapidity.

The rocks that are affected by this process are limestone, calcareous sandstone, gypsum, and salt. Silver Spring, in Marion County, Florida, is a well-known example. This spring emerges from several openings in the cavernous Vicksburg limestone into a pool several acres in extent. The volume of flow is about 385,000 gallons a minute, or 855 cubic feet a second, a stream sufficiently large to float a steamer.[1]

Lava tubular springs are due to caverns and tunnels in lava flows. These caverns and tunnels are formed through the process of igneous extrusion. When a very liquid lava cools rapidly, a crust of sufficient strength to support itself may form on the surface and the liquid lava below may flow out, leaving an arched tube. Under other conditions the crust may yield to lateral pressure of the underlying liquid lava and form arched tunnels which are made permanent by the solidification of the lava. Principally by these two processes caverns and tunnels may be produced in formations due to successive lava flows, and under favorable circumstances such openings may form channels for the ground water. On the southern flank of the mountain mass which culminates in Lassen Peak, California, large springs break out in Big Meadows, about 5 miles from Prattville.[2] The water issues from basaltic lava in an area about 100 yards in diameter. The flow is 29,000 gallons a minute, or 62.6 cubic feet a second, and the temperature is 46° F. The springs belong to a series characteristic of the lower slopes of the Lassen Peak mass, and a few of them are shown in Figure 2 (p. 533). The low temperature of these springs indicates that the water originates high up on the mountain and flows rather quickly down the slope. It seems probable that the water flows through caverns and tunnels in the lava rather than through the pores of the rock. This interpretation is supported by the existence of a similar series of springs around Mount Shasta. Plutos Cave, north of this mountain, is an example of the kind of caverns through which the water passes. It is in places 60 feet high and 50 feet wide and

[1] G. C. Matson and Samuel Sanford, "Geology and Ground Waters of Florida," *U.S. Geol. Survey, Water-Supply Paper 319* (1913), p. 367.

[2] G. A. Waring, "Springs of California," *U.S. Geol. Survey, Water-Supply Paper 338* (1915), p. 330.

has been explored for more than a mile.[1] Certain cold springs on Mount Shasta, however, appear to be due to the melting of buried ice.[2]

Minor tubular springs are due to a variety of causes (Fig. 21 *b*). The tubes or channels are of small size and irregular length, and many of them appear to be due, at least in part, to the movement

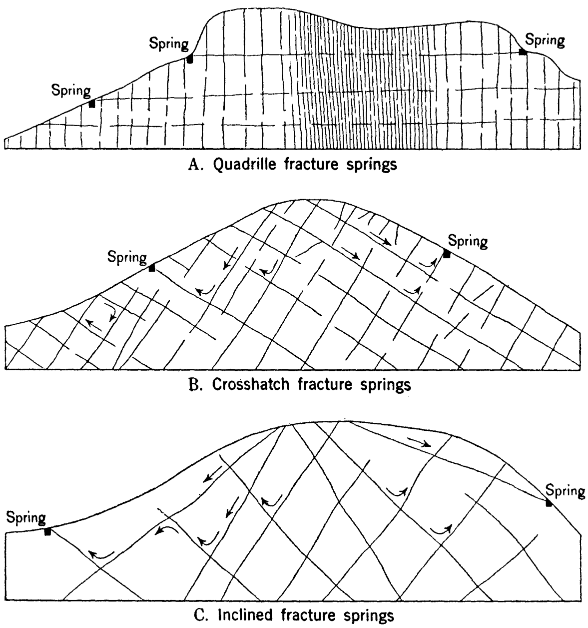

FIG. 22.—Diagram illustrating three classes of fracture springs: *a*, quadrille fracture springs; *b*, crosshatch fracture springs; *c*, inclined fracture springs.

of the water itself. Unconsolidated deposits are particularly susceptible to this action. The decay of plant roots, the existence of small sand streaks, and the enlargements of shrinkage cracks may all assist in the production of these minor openings.

2. *Fracture springs.*—Springs that issue from sheetlike or platelike openings in non-porous rocks may be called fracture springs, because such openings are primarily due to fractures. Joints,

[1] H. W. Fairbanks, *Practical Physiography* (Boston, 1906), p. 178, Fig. 180.

[2] G. A. Waring, *op. cit.*, p. 332.

bedding planes, faults, columnar joints, and openings formed on slaty cleavage, fissility, and schistosity are the common types of fractures in igneous and metamorphic rocks. In sedimentary rocks joints, bedding planes, cross-bedding planes, and faults are the principal types of fractures. If the fractures are very numerous and closely spaced, however, water moves through the rock in essentially the same fashion as in porous rocks. Minute fracture systems add very much to the effectiveness of interstitial pores and are probably present in all porous rocks. The essential difference is that in a porous rock water moves bodily, and, as a rule, slowly

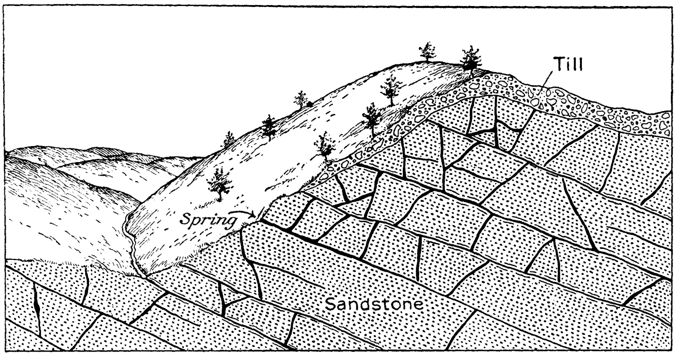

FIG. 23.—Diagram showing occurrence of springs near Mount Carmel, Connecticut. (After Gregory.)

through minute openings, whereas in fractured impervious rocks it moves more rapidly as sheets, threads, or films of water.

Fracture springs may be divided into two classes according to the attitude of the fractures toward one another and toward the horizon. A common joint system is one in which there are two or three sets of joints at right angles to one another and one of the sets is horizontal. Springs due to such joints may be called quadrille fracture springs (Fig. 22 *a*). Such a jointing system is common in sedimentary rocks and in impervious igneous rocks, particularly in sheeted plutonic rocks. Springs due to two systems of joints at right angles to each other and inclined to the horizon may be called crosshatch fracture springs (Fig. 22 *b*). Joints and bedding planes in Triassic sandstones form such a system of

fractures and give rise to springs near Mount Carmel, Connecticut, as shown in Figure 23.[1] Far more abundant, however, are irregular systems of joints, all of which are inclined toward the horizon, and springs due to such systems may be called inclined fracture springs (Fig. 22 *c*).

KEY TO THE CLASSIFICATION OF SPRINGS

I. Springs due to deep-seated waters, juvenile and connate, admixed with deeper meteoric water; do not flow under hydrostatic head and are usually not subject to seasonal fluctuation.

- A. *Volcanic Springs.* Associated with volcanism or volcanic rocks; water commonly hot, highly mineralized and containing gases. Grade from gas vents into springs of normal temperature indistinguishable from those due to other causes.
- B. *Fissure Springs.* Due to fractures extending into deeper parts of the crust; water usually highly mineralized and commonly warm or hot.
  1. Fault Springs. Associated with recent faults of great magnitude.
  2. Fissure Springs. No direct structural evidence as to origin, but because of temperature and steady flow believed to have deep origin.

II. Springs due to meteoric and occasionally other waters moving as ground water under hydrostatic head; many fluctuate in flow with the rainfall.

- A. *Depression Springs.* Due to land surface cutting water table in porous rocks.
  1. Dimple Springs. Due to depressions in hillsides.
  2. Valley Springs. Due to abrupt change in slope at edge of flood plain.
  3. Channel Springs. Due to depressions in flood plains or alluvial plains caused by channel cutting of stream.
  4. Border Springs. Due to change in slope at border between alluvial plains and playas, lake beds, or river bottoms; relative imperviousness of central clay deposits assists flow.
- B. *Contact Springs.* Due to porous rock overlying impervious rock.
  1. Impervious rock has a horizontal and regular surface.
     - *a*) Underlying bed is of large extent; common in consolidated sedimentary rock.
       - (1) Gravity Springs. Overlying material is soft.
       - (2) Mesa Springs. The overlying material is hard, usually sandstone or lava flow; water contained in pores and joints of the rock.

[1] H. E. Gregory and E. E. Ellis, "Underground Water Resources of Connecticut," *U.S. Geol. Survey, Water-Supply Paper 232* (1909), p. 136.

b) Underlying bed is of small extent; common in unconsolidated alluvium; impervious bed is usually clay, cemented gravel, "mortar bed," caliche, or hardpan.

(1) Hardpan Springs.

2. Impervious bed has an inclined and regular surface; all springs on the low side unless the overlying bed is very thick and the dip low.

a) Underlying bed is of large extent.

(1) Inclined Gravity Springs. The overlying material is soft.

(2) Cuesta Springs. The overlying material is hard; of same character as mesa springs.

b) Underlying bed is of small extent; as in hardpan springs.

(1) Impervious layer dips away from hill; spring possible.

(2) Impervious layer dips into hill; spring possible only in ravines.

3. Impervious bed has irregular surface.

a) Overlying porous material is thick and of wide extent; contact is unconformity. Gravity, inclined gravity, mesa, and cuesta springs may occur, but springs will be sharply localized at lowest parts of contact.

b) Pocket Springs. Overlying porous material is unconsolidated and more or less discontinuous, residual soil, talus, landslide débris, alluvium, till, stratified drift, wind-blown sand, or volcanic ash.

c) Overflow Springs. Irregular floor is not continuous, but porous bed is saturated and overflows at lateral contacts; common at receiving end of artesian systems.

d) Rock Dam Springs. Irregularities of the rock floor under an alluvial plain force water to surface; these may be projections of floor of basin, projections of partly consolidated older alluvium, igneous dikes, or volcanic plugs.

e) Fault Dam Springs. Dam caused by faulting.

C. *Artesian Springs*. Due to pervious bed between impervious materials.

1. Dip Artesian Springs. More or less regularly bedded rocks; tilted porous bed crops out in valley; usually sedimentary, also alternations of lava flows, flow breccias, tuffs, gravels.

2. Siphon Artesian Springs. Similar rocks; folded and with outcrops in valley.

3. Unbedded Artesian Springs. Rocks not regularly bedded, but mass of porous material is exposed so as to receive water and crops out in valley; occur in till and perhaps in other rocks.

4. Fracture Artesian Springs. All the conditions above, except that lower end of porous bed does not crop out but an opening allows water to escape. Opening due to fracturing with or without faulting.

D. *Springs in Impervious Rock:*

1. Tubular Springs. Due to more or less rounded channels in impervious rocks.
   a) Solution Tubular or Cavern Springs. Due to solution channels in limestones, calcareous sandstones, gypsum, salt.
   b) Lava Tubular Springs. Due to caverns and tunnels in lava flows.
   c) Minor Tubular Springs. Due to channels made by movement of water, decay of tree roots, sand streaks, or shrinkage cracks, usually in unconsolidated sediments.
2. Fracture Springs. Due to fractures consisting of joints, bedding planes, columnar joints, openings due to cleavage, fissility, schistosity, cross-bedding planes, and faults in impervious sedimentary, igneous, and metamorphic rocks.
   a) Quadrille Fracture Springs. Due to more or less rectangular system of fractures, one of which is parallel to the horizon.
   b) Crosshatch Fracture Springs. Due to more or less rectangular system of fractures, inclined toward the horizon.
   c) Inclined Fracture Springs. Due to inclined fractures, not necessarily systematic.